Monitoring on Site of Expanded Polystyrol to Railway Embankments

Masao Sagara
Fujita Corporation
2025-1,Ono ,Atsugi City,Kanagawa 224-0027,Japan
Tel: 046-250-7095 Fax: 046-250-7139
E-mail:sagara@fujita.co.jp

Etsuo Saitou
Fujita Corporation
2025-1,Ono ,Atsugi City,Kanagawa 224-0027,Japan
Tel: 046-250-7095 Fax: 046-250-7139
E-mail: esaito@fujita.co.jp

Kazuo Kagawa
Fujita Corporation
5-8-10,Sendagaya,Shibuya Ku,Tokyo 151-0051,Japan
Tel: 03-3356-8245 Fax: 03-3356-8265
E-mail: kkagawa@fujita.co.jp

Hiroshi Hirano
Fujita Corporation
2025-1,Ono ,Atsugi City,Kanagawa 224-0027,Japan
Tel: 046-250-7095 Fax: 046-250-7139

ABSTRACT

There are not many construction case of expanded Polystyrol(EPS) to railway embankments in Japan.
It has been a few reported that study on property of EPS to railway embankments in laboratory test. But we have been few report of monitoring on site of EPS to railway embankments. However,for site of EPS to railway embankments should be solved vibration problems under train load.
This paper describes that abstract of construction and monitoring on site of EPS to railway.
As the result of monitoring on site,its followed that this site of EPS to railway embankments is stability.

KEYWORDS: Expanded Polystyrol, EPS, Lightweight embankment, Railway embankments.

1. INTRODUCTION

The Meitetsu Tsushima Line, operated by Nagoya Railroad Co., Ltd. and connecting between the cities of Nagoya and Tsushima, plays a pivotal role in development of the northwestern area of Ama-gun, Aichi Prefecture.

The elevated railroad track construction project, herein the Project, is to build a 2.5 km long elevated railroad track between Shobata station to Tsushima station of the Meitetsu Tsushima Line. To be specific, the Project involves construction of a temporary track adjacent to the currently operated railroad track, shifting the current train service to the temporary track, construction of a new elevated track at the current track site, shifting the line back to the completed elevated track, and removal of the temporary track to complete the Project. Of the planned temporary track section, an embankment structure should be constructed for the approach section connecting the existing elevated track to the ground-level track between those two stations. Construction of such a structure involves a few difficulties. For example, the ground there is known to be relatively soft and the ground would not have a sufficient bearing capacity to resist the load of the embankment. The land itself is rented, leased to the railroad company on the condition that the original condition be restored when returned. The solution finally adopted is a lightweight embankment method that uses styrene foam (popularly referred to as "EPS" or expanded polystyrol). A 200-mm diameter concrete pile will be driven at an interval of 1 meter into the EPS embankment as reinforcement.

There are a limited number of cases where EPS is applied as embankment material for a railroad track. There are only a few in Japan [1), 2), 3)]. Of them, there is no case where EPS embankment was used for such a complicated and high-curvature (R = 300) track site as in the Project.

2. SELECTION OF TYPE OF EMBANKMENT CONSTRUCTION

The embankment work mentioned above is located at the approach from the existing elevated track of Tsushima Station, situated in a built-up area, to the ground level track spread in a rural area.

The geology is characterized by softness and fragility, with sandy or silty sand layers sandwiching two thick subsided layers, or a 2.8-m thick upper clay layer and a 14.5-m thick lower clay layer. The planned embankment rises as high as 4 to 5 m. Considering this height, an ordinary embankment is predicted to result in about 47 cm of subsidence.

Given the soft ground on which the temporary track embankment is to be built, the solution originally developed to compensate for the lack of ground-bearing capacity was ground improvement, which may include blending of ground-improving materials and soil deeper in the ground. These methods, however, were not applicable to this rental site, leasing of which requires no pile or ground-improving materials to remain in the ground. Acceptable ground reinforcing should therefore be such that will leave no foreign materials in the ground. Consequently, three plans were developed and studied, as illustrated in Fig. 2.

Plan 1 in Fig. 2 envisages improvement of the upper clay layer with cement-based solidification material mixed with the original soil by in-situ agitation; use of steel sheet piles plus tie rods for earth retaining; and application of borrow material for embankment. This method is a typical one and features a proven record of good constructibility. The catch is an expected subsidence of 21 cm at the temporary track and of 10 cm at the surrounding area (X = 10 m), with potential impacts of subsequent compaction settlement of the ground on the surrounding area.

Plan 2 uses, like Plan 1, in-situ agitation of cement-based solidifier to mix with the soft soil of the upper clay layer, applying steel sheet piles and tie rods for earth retaining and foamed mortar for embankment. Foamed mortar, a very fluid material, should play an important role in solidifying the entire work site. Unlike an ordinary embankment method, this technique dispenses with compaction, such as by rolling, of the ground and therefore is easy to work with. The technique has many applications in road embankment work and a few for railroad embankment work in recent years. The unit volumetric weight of foamed mortar is about half that of soil, from which it is expected that possible subsidence at the temporary track is 13 cm and at the surrounding area (X = 10 m) 7 cm. Possible subsidence is less than Plan 1, although negative impacts of compaction subsidence on the surroundings are still a concern.

Plan 3 involves a combination of lightweight embankment using EPS. The unit volumetric weight of this embankment assembly, including reinforcing concrete piles, is about one-tenth that of soil. Considering this, an expected subsidence at the temporary track and at the surrounding area (X = 10 m) is 6 cm and 3 cm, respectively, causing a very small impact on the surrounding. In addition, since EPS is very light in weight (19.62 N/m^3 = 20 kgf/m^3), it features a high constructibility and can take the advantage of machine-less manual labor.
Reviewing the impacts of ground subsidence on the surrounding, compliance with the rental site requirements, constructibility and economy of construction method as discussed above, Plan 3, EPS-based lightweight embankment method, was adopted.

3. CHARACTERISTICS OF EPS-BASED LIGHTWEIGHT EMBANKMENT

EPS has superior characteristics especially for its light weight, self-standing performance, water resistance, and constructibility.

For light weight characteristics, the unit volumetric weight is around 0.196 kN/m^3 (= 0.02 tf/m^3, about 1/100 that of soil), wh ich makes it suitable for the type of ground with no sufficient bearing capacity as it can successfully reduce the load of embankment on such ground. EPS also features a high self-standing performance. When EPS blocks (each block measuring 1000 × 2000 × 500 mm; see Photo 1) are piled up, self-standing sides are formed. Since the Poisson ratio of such a self-standing side is almost 0, it may be used as a self-standing wall.

As for water resistance, EPS is water repellent by itself, and is a conglomerate of foamed particles that defy absorption of water into themselves, therefore can prevent change of material characteristics.

For constructibility, since EPS is light weight, no heavy machinery is required; human power is enough to do the job and that quickly. This feature makes it an optimum choice for locations where it is difficult or impossible to bring in or use heavy machinery due to the restrictions of the topography or the geology at the work site.
Thus, EPS can outperform other ordinary embankment materials as a lightweight embankment material particularly when applied to soft ground.

4. OVERVIEW OF CONSTRUCTION

The EPS-based lightweight embankment method was applied for the above-mentioned work (herein the Work) according to the following procedure. Fig. 3 shows a typical section of the EPS embankmentl.

? Sand mat
? Sand drain (ground improvement)
(Sand mat: t = 300 mm; sand drain: ƒ 400@1700 mm, 203 drains (3 drains per 10 m^2))
To promote compaction during embankment work by loading, the injection-type gravel drain method was employed to improve the ground.
? Driving of steel sheet piles (steel sheet pile: Type III, L = 11, 12 m)
Sheet piles were driven first to the side closer to the operating line to prevent settlement of the embankment.
? Embankment
Earth was embanked up to H = 1.8 m (including the thickness of the sand mats or t = 300mm), equivalent to the load during operation of the temporary track 26.49 kN/m^2 (= 2.7 tf/m^2). 96% compaction of the expected subsidence (15 cm) was assumed. 15 cm of subsidence on site was confirmed by subsidence plates.
? Removal of embankment
? Driving of steel sheet piles (steel sheet pile: Type III, L = 11, 12 m)
Steel sheet piles should be driven to set up a final steel sheet pile + Tible anchored retaining wall.
Since EPS was to be applied at an unfavorable topography, or R = 300 m and a longitudinal gradient of 25.6‰, a large lateral load was expected to occur due to the centrifugal load of a train running at this site. Assuming a train runs at 100 km/h, lateral displacement at the top of the steel sheet pile was calculated to be 10 mm.
Given the primary control value of the track maintained by Nagoya Railroad is ± 5.0 mm in vertical placement and ± 3.0 minutes in slope, dynamic observation was conducted to ensure safety at this portion of the track.
? Foundation rubble bed (t = 200 mm)
? Lower RC slab (t = 100 mm; welded net: ƒ 6@150 mm)
? Drainage piping
(ƒ 100@5000mm for lower; ƒ 75@5000 mm for upper)
? Water permeable mat (t = 10 mm)
Water permeable mats were installed to help water from upstream flow swiftly into side drains. They also help adjust EPS unevenness.
? EPS embankment + Tible anchor + fill sand
(Tible:F50T, L = 9000@1600 mm; EPS: standard block, 1000 × 2000 × 500 mm)
EPS shows elastic behavior for repeated loading within a certain range of strain. Generally speaking, when EPS

shows elastic behavior due to repeated loading within the tolerable range of compressive strain, compressive strain of EPS is less than 1%. Since the total load imposed on EPS goes to 41.10 kN/m^2 (= 4.19 t/m^2) including train load and dead loads (track, ballast, RC slab), the type of EPS to be used for the Project is Esren Block D-20 (tolerable compressive stress of 49.05 kN/m^2 = 5 tf/m^2). Photo 2 shows how the first row of EPS blocks is applied.

? Intermediate RC slab + concrete pile
(Intermediate slab: t = 100 mm; welded net: ϕ6@150 mm; concrete pile: ϕ200 mm)
RC slab prevents entering of rainwater, grease, or fat from up or railroads as well as eliminating EPS exposure to direct sunshine (ultraviolet ray). It also enhances the durability of floor slabs to disperse stress, which will help reduce stress to be imposed on EPS. Generally, typical railroad track embankment can provide an effective reduction in dynamic displacement with the floor slab as thick as up to 40 cm. Even when the slab is thicker than that, further loading reduction will not be expected. Therefore, calculating the optimum slab thickness based on the above loading, t = 100 to 200 mm was obtained.
Concrete piles were installed to reduce dynamic displacement by train loads and enhance compressive rigidity of EPS. Addition of 2% mortar to EPS only is found by some research to be effective in raising the level of initial rigidity four times[1). Since mortar improvement conducted to the EPS for the Work by using concrete piles (ϕ200@1000 mm) is 3.14%, it is fair to expect over four-fold enhancement of initial rigidity of the EPS composites.

? EPS fill + Tible + fill sand

? Upper layer RC slab + concrete pile (upper slab: t = 150 to 200 mm; reinforcement D13@150 mm)
Photo 3 shows concrete piles driven after installation of EPS blocks from the 1st to 12th row.
Photo 4 shows placement of upper RC slab concrete.

5. MEASUREMENT OF DYNAMIC BEHAVIOR OF EPS EMBANKMENT

Three measurements, as follows, were made to understand dynamic behavior of the EPS embankment. (See the measurement map in Fig. 7.)

? Floor slab subsidence as measured with accelerator
An accelerator was installed on the floor slab (shown as Ac-1 to 12 in Fig. 7) to measure acceleration in the floor slab in the vertical direction during the passage of a train. Integrating the measured vertical acceleration twice can convert the value to displacement, which lead to calculating the subsidence of the floor slab as the train passes. A displacement gauge was also installed at both ends of the floor slab to measure dynamic subsidence of the floor slab in the vertical direction.

? Train loads as measured with earth pressure gauge
Earth pressure gauges were installed at five locations (L-1 to L-5) at the top of the floor slab to measure load distribution during the passage of a train.

? Measurement of dynamic behavior of the floor slab with strain gauge
A set of two measuring rebars (D13mm, each measuring 11 points (two gauges)) was embedded each for the upper part and lower part at the predetermined measurement section of the floor slab to measure bending mo ment of the slab during the passage of a train.

6. MEASUREMENT RESULTS AND DISCUSSION

Values shown in Figs. 4 to 6 are the results of measurement made during the passage of ten trains in the down line. Each value is the maximum reading of each passage and the average of all those maximums are shown in the figures. The lateral axis in each figure shows measurement points, for which the measurement point map of Fig. 7 may be referred to.

? Residual deformation of EPS embankment structure (measurement with accelerator)
Fig. 4 shows the values for train passages in the down line as measured by accelerators. Vertical subsidence at each position calculated from the measured acceleration is shown in the figure. As indicated by those results, there is vertical subsidence, of which maximum goes up to only about 0.5 mm. Although not shown in the figure, subsidence measured with laser displacement gauge was approximately 0.02 to 0.3 mm. These readings are far below the field control standard of 5.0 mm, indicating the resultant subsidence being unlikely to cause any

hazard to safety management.

Regarding residual deformation by dynamic impact, according to a research [1] of the Railway Technical Research Institute, it is reported that no residual displacement is observed for the EPS embankment structure improved by 2% mortar after the improved embankment underwent a cycle of repeated loading test including a displacement amplitude of 1.0 mm and exciting frequency of 20 Hz. The mo rtar improvement ratio of the EPS embankment used for the Work is 3.14%, which is higher than the previously discussed EPS embankment (improvement ratio of 2%) and the subsidence measurement results include about 0.5 mm as a maximum (< 1.0 mm). Given these results, it is concluded that the EPS embankment for the Work will cause no residual deformation due to dynamic impact.

? Train loads (measurement made with earth pressure gauge)

Fig. 5 shows the results of earth pressure measurements made on the down line. The value immediately under the track (L-2) is 172.6 kPa (17.61 tf/m^2), while that almost at the center of the track (L-1) is 117.8 kPa (12.02 tf/m^2). It is concluded that these values will not cause any major impact on the embankment with respect of train loads since the mortar improvement ratio of the EPS embankment is 3.14% and its strength over four times that of EPS (196.28 kPa (20.00 tf/m^2)) is expected to be obtained. It should be noted that the train load was treated as distributed load in a static design and that those dynamic measurements presented here are not in the form of distributed load. This point needs to be discussed as one of future issues in designing EPS embankment.

? Distribution of bending moment of the floor slab (measurement made with strain gauge)

Fig. 6 shows bending moment distribution of the floor slab obtained from strain gauges. For symbol of bending moment, when downward convex is made on the floor slab, its direction is taken as positive. For the value of bending moment, the maximum is about 2.238 kN·m (= 0.228 tf·m) (the range being from 0.206 to 2.238 kN·m (= 0.021 to 0.228tf·m) and about 10×10^{-6} for reinforcement strain). This value is smaller than the maximum of bending moment required for design, or about 2.943 kN·m (= 0.3 tf·m), and therefore it is considered there will be no impact of bending moment generated by train loads on the floor slab.

7. CONCLUSION

Dynamic measurement indicated that there will be almost no impact of train loads on EPS embankment and it is concluded that the EPS embankment employed for the Work will be stable. At the work site, measurement for subsidence of the EPS embankment still continues after the preparation of this report and there is only a little subsidence observed at the point of four months after completion of the Work. These observations also indicate the EPS embankment is in the stabilized condition. However, there are not many application cases of this method and the ground is so soft by nature that there would occur subsidence of the entire EPS embankment in the future. Continued measurement for subsidence is therefore determined.

ACKNOWLEDGEMENT

The authors express their great respect and thanks to Nagoya Railroad Co., Ltd. for their aggressive introduction of new technologies and also acknowledge other parties concerned for provision of technical guidelines.

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MESSAGE FROM AUTHOR

It is the pleasure of the authors that this report will be of any help to all engineers and specialists engauged in EPS method.

Fig. 1 Map of Meitetsu Tsushima Line

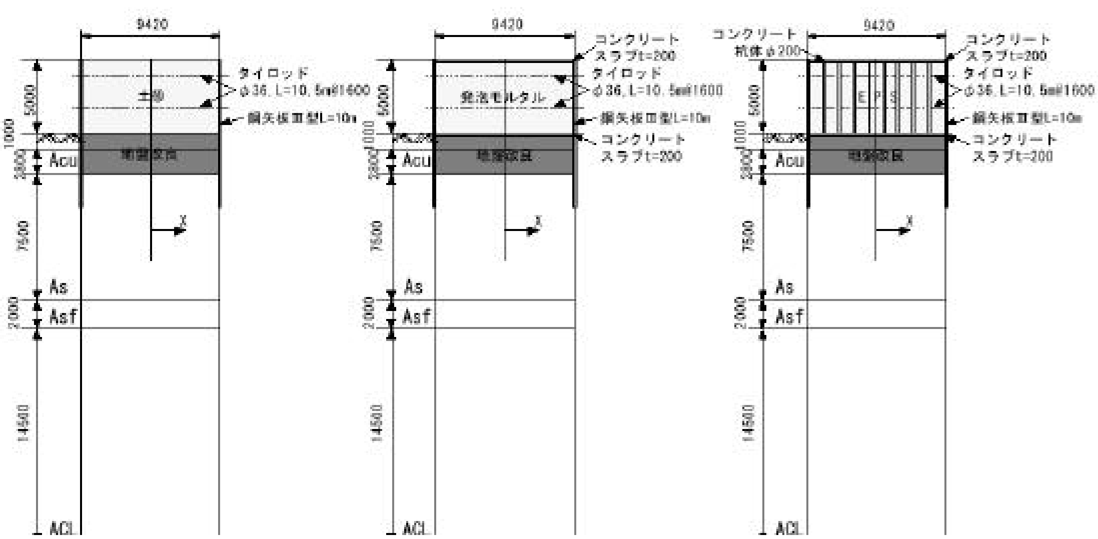

Photo 1　EPS block (1000 x 2000 x 500mm)

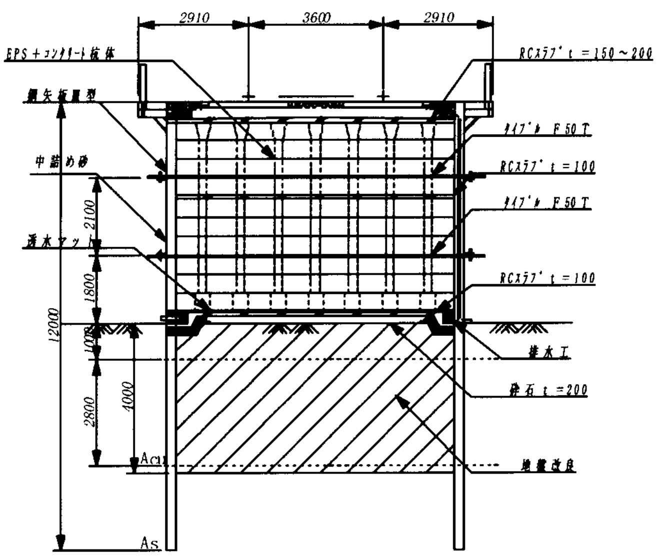

Fig 3　Typical section

Fig. 4 Dynamic subsidence measurement

Photo 2 Installation of EPS blocks - first row

Photo 3 Installation of EPS blocks - 1st to 12th row completed

Phc

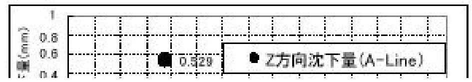

Fig. 5 Earth pressure measurement

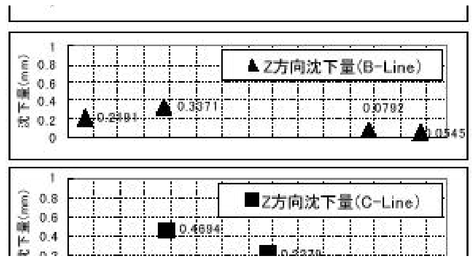

Fig. 6 Bending motion

図 4 動的沈下量測定結果

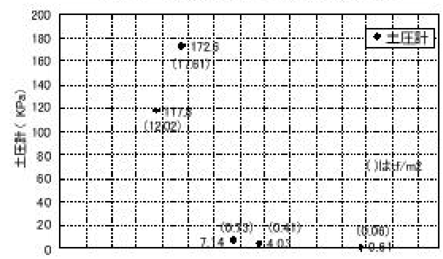

図 5 土圧計測結果

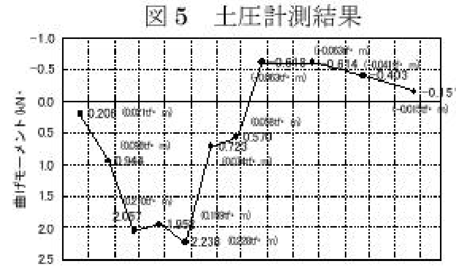

図 6 曲げモーメント図

Fig. 7 Measuring points